# MODELING AN AUTOMATIC ADJUSTMENT OF SCANNING RATE USING FUZZY INFERENCE LOGIC

Hyun W. Ka, MS; Richard C. Simpson, PhD, ATP
Department *of Rehabilitation Science and Technology, University of Pittsburgh*
6425 *Penn Ave, Suite 401 Pittsburgh PA 15206*
{hyk21, ris20}@pitt.edu

## INTRODUCTION

Single-switch scanning is one of the slowest ways for people with severe motor impairments to access a wide range of assistive technologies, such as entering text into computer applications, manipulating alternative and augmentative communication devices, and operating power wheelchairs. Automating scanning rate adjustment has been investigated as a means of improving selection rate by several research groups [1-6], using probabilistic methods such as uncertainty factors and Bayesian networks. In practice, however, when assessing and documenting their client's needs, clinicians tend to prefer specifying linguistic values, such as slow, medium, and fast, rather than numerical values. In this respect, fuzzy logic can be an alternative to existing approaches because it can capture the meaning of linguistic variables whose values are words rather than numbers [7, 8]. This paper describes our approach to modeling the automatic adjustment of scan rate using fuzzy logic.

## FUZZY LOGIC

Unlike two-valued conventional Boolean logic, fuzzy logic is multi-valued. Fuzzy logic is based on fuzzy set theory, whose basic idea is that an element belongs to a fuzzy set with a certain degree of membership. Thus, fuzzy logic can deal with degrees of truth using the continuum of real numbers between 0 (completely false) and 1 (completely true). For example, conventional Boolean logic maps all elements to a set A by a function $f_A(X)$ called the characteristic function of A,

$f_A(X) = \{0, 1\}$

where

$f_A(X) = 1$ if x is an element of set A

$f_A(X) = 0$ if x is not an element of A

In fuzzy logic, set A is defined by function $\mu_A(X)$ called the membership function of set A,

$\mu_A(X) = [0, 1]$

where

$\mu_A(X) = 1$ if x is totally in A

$\mu_A(X) = 0$ if x is not in A

$0 < \mu_A(X) < 0$ if x is partially in A

The value between 0 and 1 represents the degree of membership of element x in set A.

Determining the range of possible values of a linguistic variable, establishing membership functions and constructing fuzzy rules are three basic steps for using fuzzy logic as an inference tool.

The range of possible values of a linguistic variable represents the *universe of discourse* of that variable. For example, the universe of discourse of the linguistic variable 'switch press time' might have a range of 0 to 3 seconds and may include such fuzzy subsets as slow, medium, and fast. In order to more precisely capture the meaning of a linguistic variable, fuzzy set theory provides the concept of fuzzy set qualifiers (called hedges) [9], which are usually represented by adverbs such as very, somewhat, quite, more or less, and slightly, and modify the shape of a fuzzy set. For example, *very* reduces the degree of membership in a set, while *more or less* expands a set and increases the degree of membership.

Similar to conventional set theory, fuzzy set theory provides basic operations such as union, intersection, complement and containment. In the case of the union operation, while conventional sets determine which elements belongs to either set, fuzzy sets ask how much of the element is in either set. For the operation of intersection, while crisp sets focus on which elements belongs to both sets, fuzzy sets are interested in how much of the element is in both sets. For the operation of complement, while conventional crisp sets are interested in who does not belong to the set, fuzzy sets focus on how much elements do not belong to the set.

In order to establish an appropriate membership function, it is necessary to convert a linguistic variable into a fuzzy set and then to map the elements of the set to their degree of membership. Several functions are used to do this, including linear fit, Sigmoid, Gaussian and pi function.

A fuzzy rule can be defined as a conditional statement in the form:

IF x is A

THEN y is B

where x and y are linguistic variables, and A and B are linguistic values determined by fuzzy sets on the universe of discourses X and Y, respectively. For example, when adjusting scan rate, AT clinicians may construct the rules, such as if the switch press time is fast, then scan rate should be fast; if the error rate is high, then scan rate should be very slow. Any rule consists of two parts: the if-part of the rule is called *antecedent* or *premise*, and the then-part of the rule is called *consequent* or *conclusion*. In fuzzy logic, if antecedent is true to some degree of membership, then consequent is also true to that same degree.

In summary, the typical process to apply fuzzy inference logic to decision making consists of five steps: (1) fuzzification, which takes the input and output variables and determines the degree to which they belong to each of the appropriate fuzzy sets via membership functions; (2) application of the fuzzy operation in the antecedent; (3) implication from the antecedent to the consequent; (4) aggregation of the consequents across the rules; and (5) defuzzification which generates a single crisp number based on the aggregation [7]. There are several defuzzification methods [7], but the most popular one is the centroid technique called Mamdani function. It finds center of gravity (COG) where a vertical line would slice the aggregate set into two equal masses (Figure 1).

$$\mathrm{COG} = \frac{\int_a^b \mu_A(x)x\,dx}{\int_a^b \mu_A(x)\,dx}$$

Figure 1. Mathematical Expression of Center Of Gravity (COG)

## MODELING AUTOMATIC ADJUSTMENT OF SCAN RATE USING FUZZY LOGIC

Factors that affect communication rate with a single switch scanning system include the layout of selections, the timing parameters, and the use of additional communication rate enhancement techniques such as word prediction. Since the focus of this research is on automating scanning rate adjustment using fuzzy inference logic, only the timing parameters, including switch press time and frequency of timing errors are used as input variables, and recommended scan rate is the only output variable. Switch press time refers to the average time to activate the switch when the target was highlighted. Frequency of timing errors is the percentage of targets during which the user either pressed the switch when the target was not highlighted or failed to press the switch when the target was highlighted. Scan rate refers to the amount of time an item remains highlighted for the user to make a selection. If the system’s scan rate is too long then the user will spend too much time waiting and communication rate will be less than optimal. On the other hand, if the system’s scan rate is too short then the user’s timing errors will increase, which will also decrease communication rate. In either case, the user’s comfort and satisfaction with the system will be compromised.

Simpson and colleagues [6] discovered that the ratio between a user’s switch press time and an appropriate scan rate for that user is approximately 0.65, which they called ‘the .65 rule’. The membership functions for fuzzification in this research were established based on the .65 rule.

The basic structure of our model for automatic adjustment of scanning rate is a two-input, one-output fuzzy inference system (Figure 2).

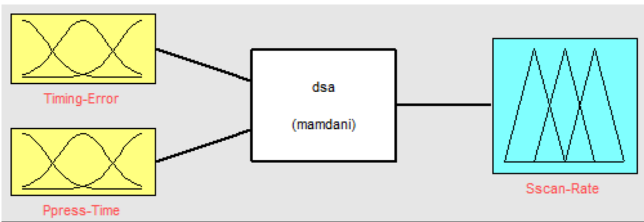


Figure 2. Basic Structure of the Fuzzy Model

As the first step to developing the model, we took two input and one output variables (switch press time, frequency of timing errors and scan-rate) and determined the range of possible values of a linguistic variable (fast, medium, slow, high, and low) and set up appropriate membership functions associated with each variable (Switch Press Time in Figure 3, Frequency of Timing Errors in Figure 4, and Scan-Rate in Figure 5).

Then, based on the descriptions of the input and output variables, the following five rules were constructed:

IF Switch Press Time is fast THEN Scan-Rate is fast

IF Switch Press Time is medium THEN Scan-Rate is medium

IF Switch Press Time is slow THEN Scan-Rate is slow

IF Frequency of Timing Errors is low THEN Scan-Rate is very fast

IF Frequency of Timing Errors is high THEN Scan-Rate is very slow

The order of the rules is arbitrary. It does not matter which rule comes first, since all rules fire. The range of each linguistic variable is subject to clinical assessment, but the five rules are generally universal.

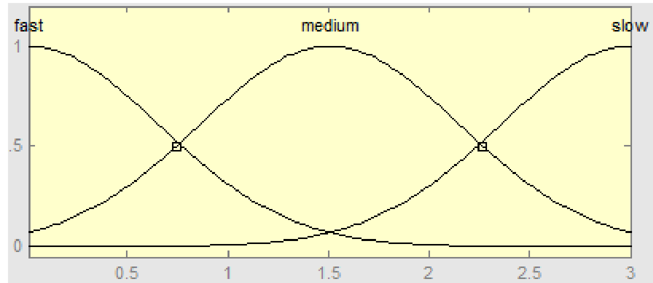


Figure 3. Membership Function for Input Variable “Press-Time”

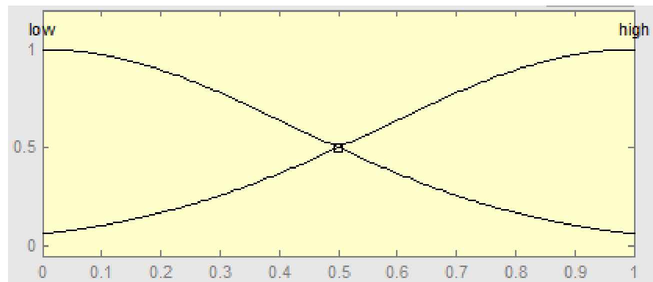


Figure 4. Membership Function for Input Variable “Timing-Error”

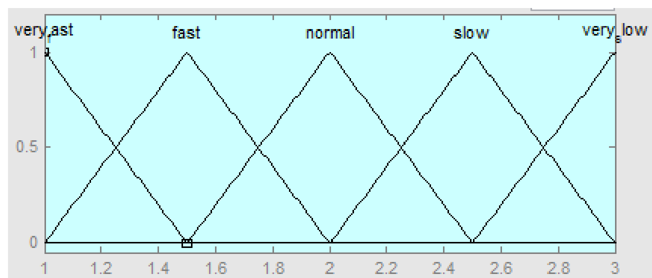


Figure 5. Membership Function for Input Variable “Scan-Rate”

Integrating the above rules along with the variables and the membership functions into fuzzy inference logic, the following model is obtained which illustrates automatic adjustment of scanning rate (Figure 6).

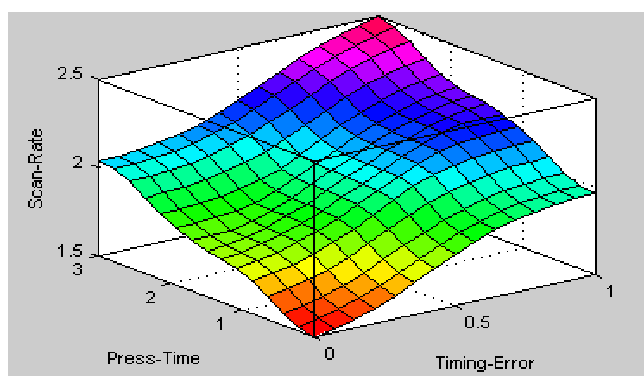


Figure 6. Surface Plot of Automatic Scanning Rate Adjustment Model

## DISCUSSION

Benefits from the model of fuzzy-based automatic scanning rate adjustment include: it performs faster than conventional rule-based models and requires fewer rules [10]; it provides a means of computing with words that reflects how human experts practice their expertise [8]; it can help to represent the expertise from multiple experts even when they have opposing views [11]. However, in spite of these benefits, it is still appropriate that clinicians play a central role in configuring assistive technology, because the system depends on the rules extracted from the experts.

Future directions include collecting empirical data from clinical trials.

## ACKNOWLEDGEMENTS

This work is supported by National Science Foundation Quality of Life Technology Engineering Research Center (NSF QoLT ERC) #0540865.

## REFERENCES

[1] S. Cronk and R. Schubert, "Development of a real time expert system for automatic adaptation of scanning rates," 1987, pp. 109–111.

[2] G. Lesher, *et al.*, "Techniques for automatically updating scanning delays," 2000, pp. 85-87.

[3] G. Lesher, *et al.*, "Acquisition of scanning skills: The use of an adaptive scanning delay algorithm across four scanning displays," 2002.

[4] R. Simpson and H. Koester, "Adaptive one-switch row-column scanning," *Rehabilitation Engineering, IEEE Transactions on,* vol. 7, pp. 464-473, 2002.

[5] R. Simpson, *et al.*, "Evaluation of an adaptive row/column scanning system," *Technology and Disability,* vol. 18, pp. 127-138, 2006.

[6] R. Simpson, *et al.*, "Selecting an appropriate scan rate: the". 65 rule"," *Assistive technology: the official journal of RESNA,* vol. 19, p. 51, 2007.

[7] E. Cox, *The fuzzy systems handbook*: AP Professional Boston, 1994.

[8] L. Zadeh, "Fuzzy sets*," *Information and control,* vol. 8, pp. 338-353, 1965.

[9] L. Zadeh, "A fuzzy-set-theoretic interpretation of linguistic hedges," *Cybernetics and Systems,* vol. 2, pp. 4-34, 1972.

[10] E. Cox, *The fuzzy systems handbook*. Boston: AP Professional, 1998.

[11] E. Turban and J. Aronson, *Decision support systems and intelligent systems*: Prentice Hall, 2005.